2018 DOE Vehicle Technologies Office Review Presentation

Functionally Designed Ultra-lightweight Carbon Fiber Reinforced Thermoplastic Composites Door Assembly

Project ID: mat118

Principal Investigator: Dr. Srikanth Pilla
Department of Automotive Engineering
Department of Materials Science and Engineering
Clemson University

June 7th, 2018

Overview

Timeline

- Start: December 1, 2015
- End: January 31, 2020
- 50% Complete

Budget

- Total project funding
  - $2,249,994 (DOE)
  - $3,117,759 (Cost-share)
- Funding received in FY 15:
  - None
- Funding for FY16
  - $642,819 (DOE)
  - $871,357 (Actual Cost-share)
- Funding for FY 2017
  - $624,023 (DOE)
  - $674,889(Actual Cost-share)
- Funding for FY 2018
  - $643,242 (DOE)
  - $780,817(Proposed Cost-share)

Barriers

- Cost/Performance
  - High cost of CFRP is the greatest barrier to the market viability of advanced composites for automotive lightweight applications.
  - Meeting CFRP-Thermoplastics performance to satisfy/exceed fit, function, crash and NVH at desired cost.
- Predictive tools
  - Integration of predictive models between systems (design/geometry/process/analysis) and at all length scales.

Core-Partners

- Clemson University
- University of Delaware
- Honda North America

Relevance - Project Objectives

1. Achieve a 42.5% weight reduction (addresses goals in the DOE-VT MYPP)
   - Base weight = 31.8 kg
   - Target Weight = 18.28 kg

2. Zero compromise on performance targets
   - Similar crash performance
   - Similar durability and everyday use/misuse performance
   - Similar NVH performance

*Image provided by OEM partner

3. Maximum cost induced is 5$ per pound. (.453 kg)
   - Allowable cost increase = [(31.8-18.28)/.453]*5 = $ 150.1 per door

4. Scalability
   - Annual production of 20,000 vehicles

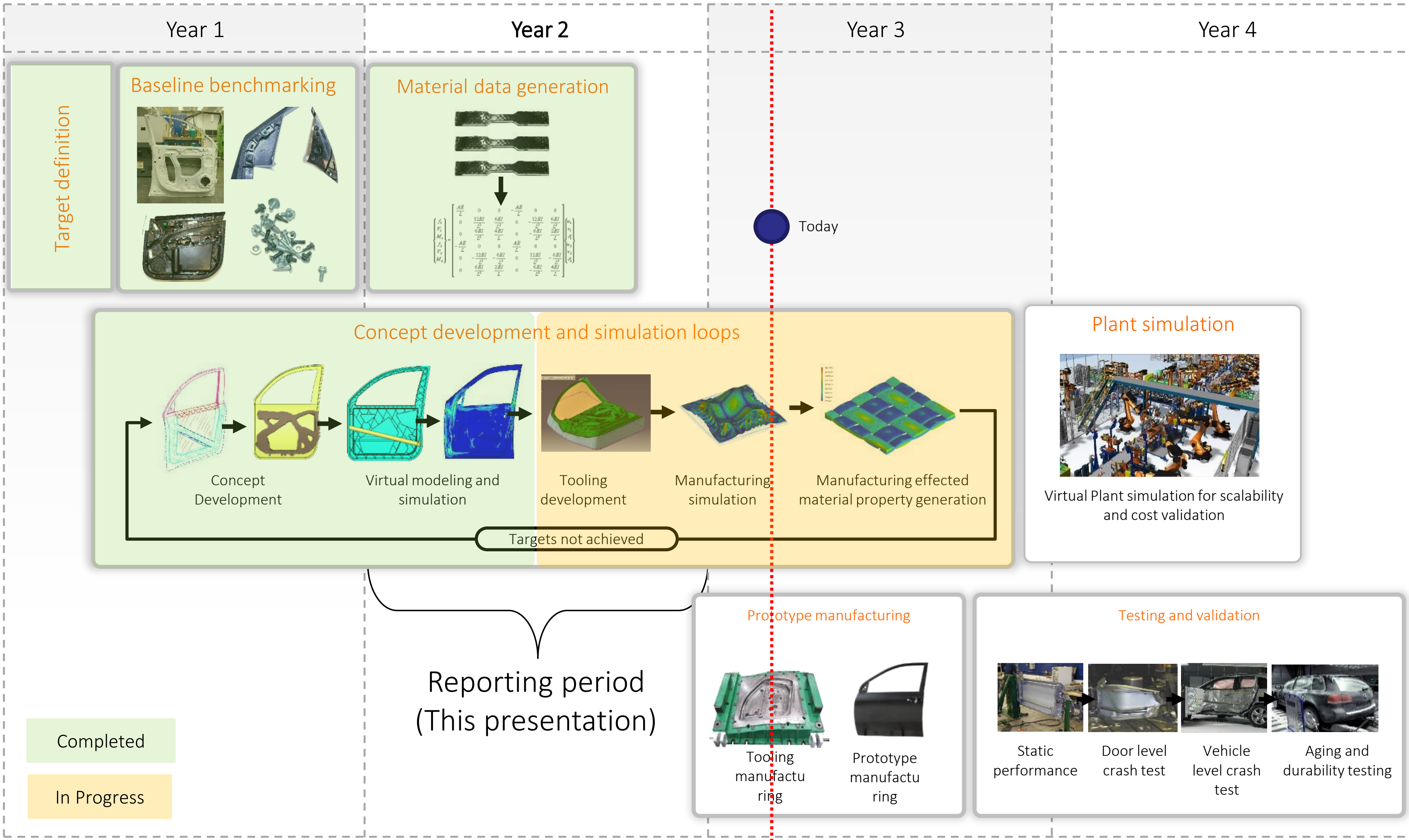
5. Recyclability
   - European standards require at least 95 % recyclability
   - Project goal is 100% recyclable (self imposed)

Milestones

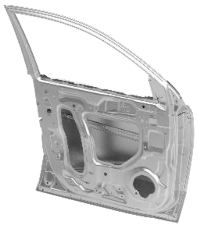
- ✓ Establish design criteria (Fy 2015-2016; Q2)
- ✓ Develop a detailed target catalogue (Fy 2015-2016; Q2)
- ✓ Create a test and evaluation plan (Fy 2015-2016; Q2)
- ✓ Benchmark the current door (Fy 2015-2016; Q3)
- ✓ Test and catalogue commercially available materials (Fy 2015-2016; Q4)
- ✓ Design and develop three functional door concepts that can meet project targets. (Fy 2015-2016; Q4)
- ✓ Down select design concept for concept detailing (Fy 2016-2017; Q3)
- ✓ Design optimization for linear load cases (Use and miss-use) (Fy 2016-2017; Q4)
- ✓ Cost Estimation For all design concepts (FY 2016-2017 Q4)
- ⚠ In progress - Design optimization for non-linear load cases (Crash requirements) (Fy 2017-2018; Q2)
- ⚠ In progress - Tooling design (Fy 2017-2018 Q3)

Approach

*Images are for example only



Progress -Target Definition

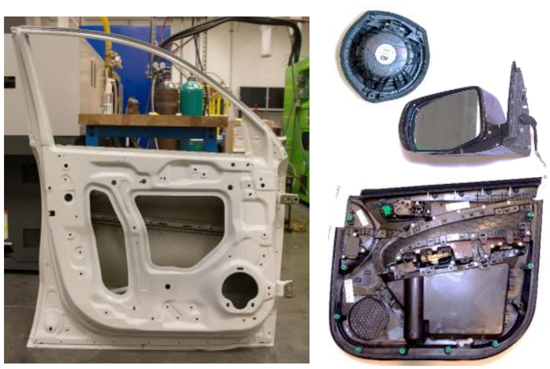


Frame 60% Reduction
Current weight : 15.45 kg
Target weight target : 6.18 kg

Electronics 0% Reduction
Current weight : 3.0 kg
Target weight target : 3.0 kg

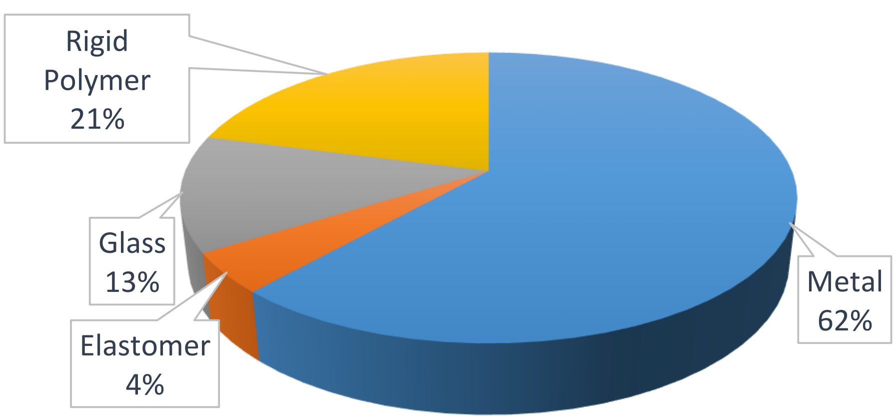
Window 20% Reduction
Current weight : 3.70 kg
Target weight target : 2.77 kg

Trim 30% Reduction
Current weight : 3.24 kg
Target weight target : 2.26kg



Teardown Benchmarking

Mass Distribution in the baseline door

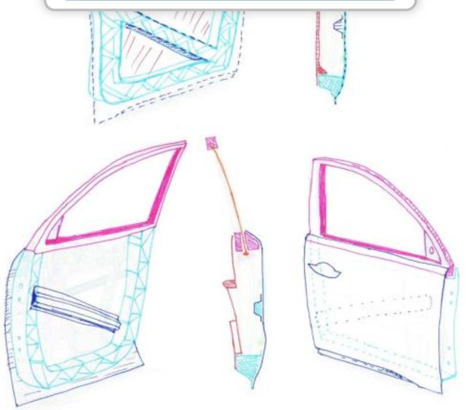


Progress - Concept Development

*Images are for example only

Phase 1
Q2 2016

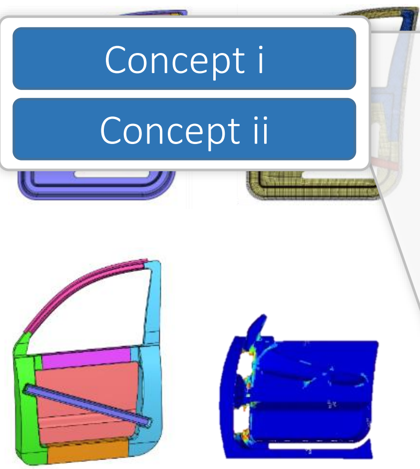
- Concept A
- Concept B



- Hand drawn sketch.
- High level material selection.

Phase 2
Q2 2016

- Concept i
- Concept ii



- Rough cad models using generic door geometries.
- Initial FEA for simple static load cases.

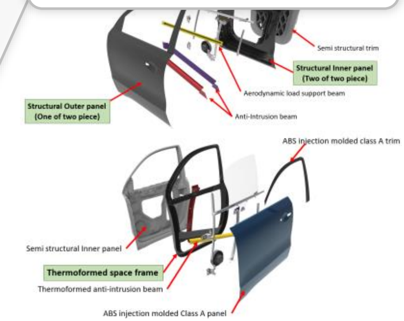
Phase 3
Q4 2016

- Concept 1
- Concept 2
- Concept 3
- Concept 4
- Concept 5
- Concept 6
- Concept 7

- Design workshop was conducted at CUICAR.
- Complete team agreed on 7 concepts for door frame.
- Most of these concepts were hand sketched.

Phase 4
Q3 2017

- Concept 2
- Concept 4
- Concept 7



- Detailed CAD models were generated.
- FEA was performed to validate static performance in compliance with Honda's targets.

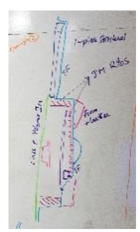
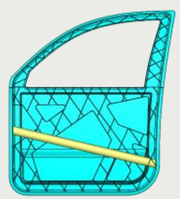
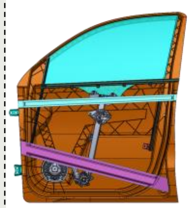
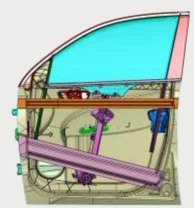
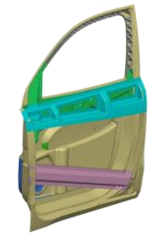
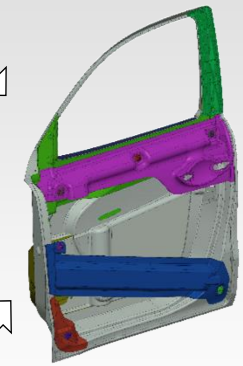
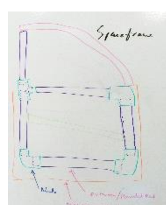
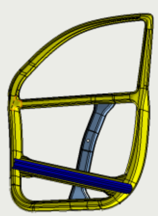
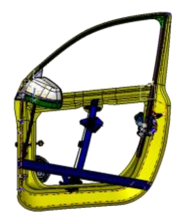
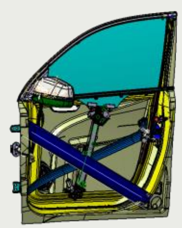
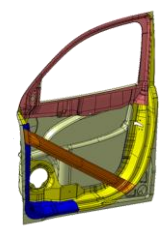
Progress - Concept Development

2016 Q3 : Down selected from 7 concepts to 2

	Concept 2 	**Concept 4** 	**Concept 7** 
No.of structural parts in the frame	**1**	**2**	**1**
Exterior Class “A” panel	Removable non-structural	Fixed structural	Removable non-structural
Interior Trim	Integrated into the frame	Semi structural	Non-Structural
Core manufacturing technologies	Thermoforming with over molded LFT	Thermoforming	Injection molding with thermoforming
Parts consolidation potential	Very high	Medium	Low
Easy of assembly	Very Easy	Similar to baseline	Easy

Progress - Concept Development

Design development and evolution over 12 months.

	Q3 (2016)	Q3 (2016)	Q4 (2016)	Q2 (2017)	Q3 (2017)	Q4 (2017)
Concept 2 Integrated frame						
Concept 7 Space Frame						

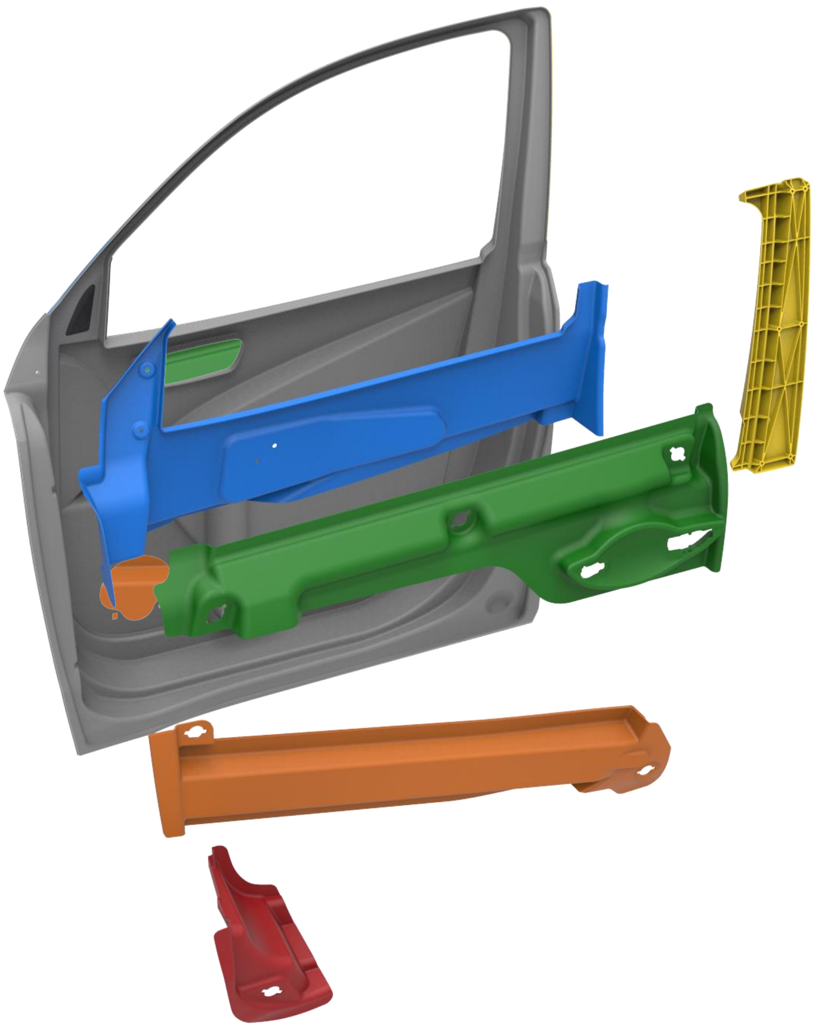
Progress - Concept Development

Final Design Concept :

All door subsystems can be divided into 4 major categories

1. Interior trim
2. Inner frame
3. Door internals
4. Class A panel

Progress - Concept Development



Structural components of inner panel

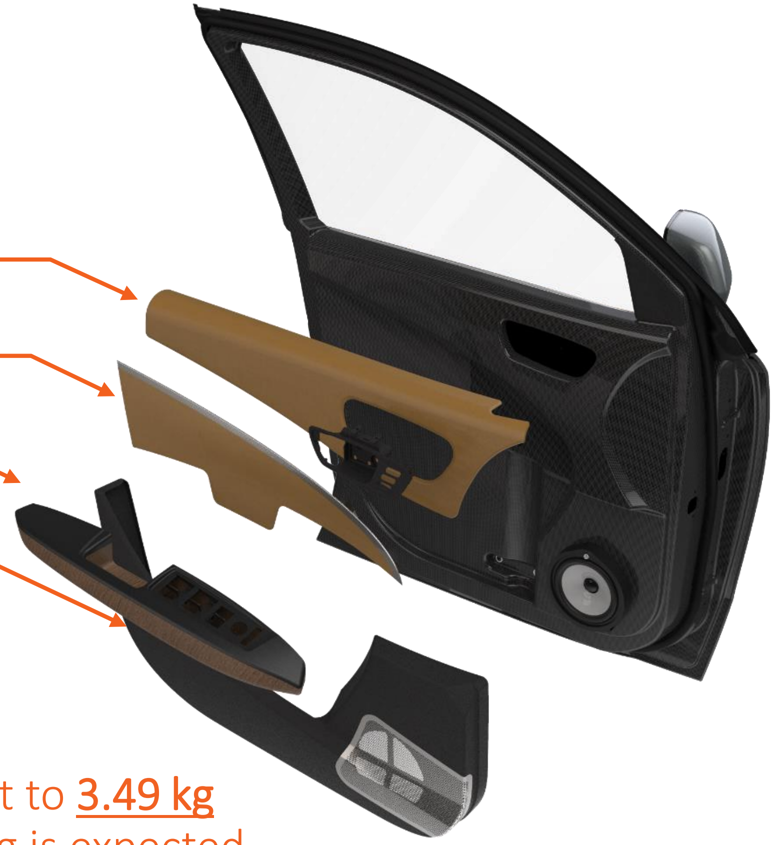
1. Inner frame
   - Thermoformed inner panel with integrated trim.
   - Material: Non-Woven fabric with UD reinforcements.
2. Anti intrusion beam
   - Thermoformed hat section with a spine.
   - Material: UD tapes, mostly ±45°.
3. Inner beltline stiffener
   - Thermoformed shell with mounting interfaces for the inner components.
   - Material: Non-Woven fabric with UD reinforcements.
4. Outer beltline stiffener
   - Thermoformed shell with mounting interfaces for the inner components.
   - Material: Non-Woven fabric with UD reinforcements.
5. Lower hinge stiffener
   - Thermoformed shell part.
   - Material: Non-Woven fabric.
6. Sash reinforcement
   - Injection molded
   - Material: Nylon with long/short carbon fiber.

Progress - Concept Development

To minimize weight and cost, this concept has no interior panel. Instead it has a few injection molded parts to meet functional requirements.

Non-structural trim components

1. Upper padding
   - Leather laminated with foam.
2. Middle padding
   - Leather laminated with foam.
3. Hand rest
   - Natural wood, back molded with ABS
4. Map pocket
   - Injection molded Carbon fiber SFT or ABS



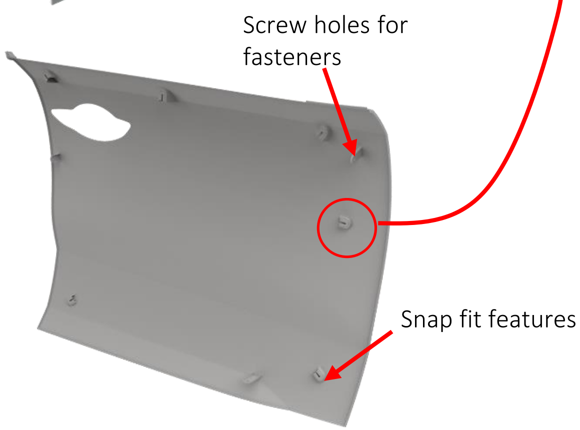
These parts weigh approximately 1.34 kg in contrast to 3.49 kg in baseline door. Further weight reduction of 0.25Kg is expected with optimization.

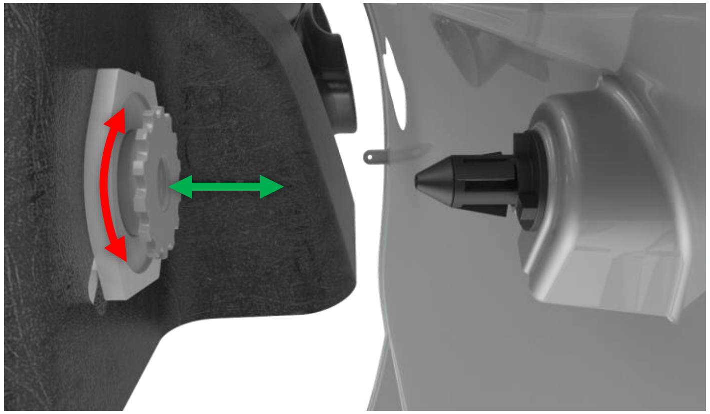
Progress - Concept Development

Outer panel is injection molded ABS or PP, and has features for snap fits and fasteners located on its inner side.

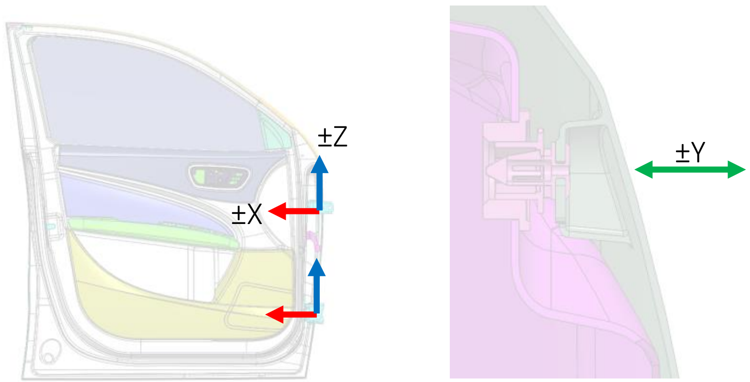
Outer Side

Inner Side





Snap fits with adjustability, to compensate for manufacturing tolerances.



Progress - Concept Development

Internal

Strength

- Much lower part count
- Energy efficient manufacturing processes
- Good access to door internal components, thus enabling easier and cheaper assembly
- Better dent resistance
- Highest lightweight potential
- Design freedom to enable part consolidation and functional integration

Weaknesses

- Thermoforming processes for thermoplastic composites have less historical knowledge
- Relatively poor NVH properties
- Integrating with steel side frame is not an ideal scenario
- High raw material cost

External

Opportunities

- Materials and technologies developed for this door can easily be scalable to other automotive components (E.g. Hang on and BiW parts)
- Relatively lower infrastructure cost can enable new OEMs and suppliers to implement these technologies

Threats

- Door cost is highly sensitive to raw material cost
- Lightweight metal alternatives have an economic advantage
- OEMs and suppliers might show resistance to embrace new materials and manufacturing processes
- Raw material supply chain for thermoplastics composites is not as robust as metals

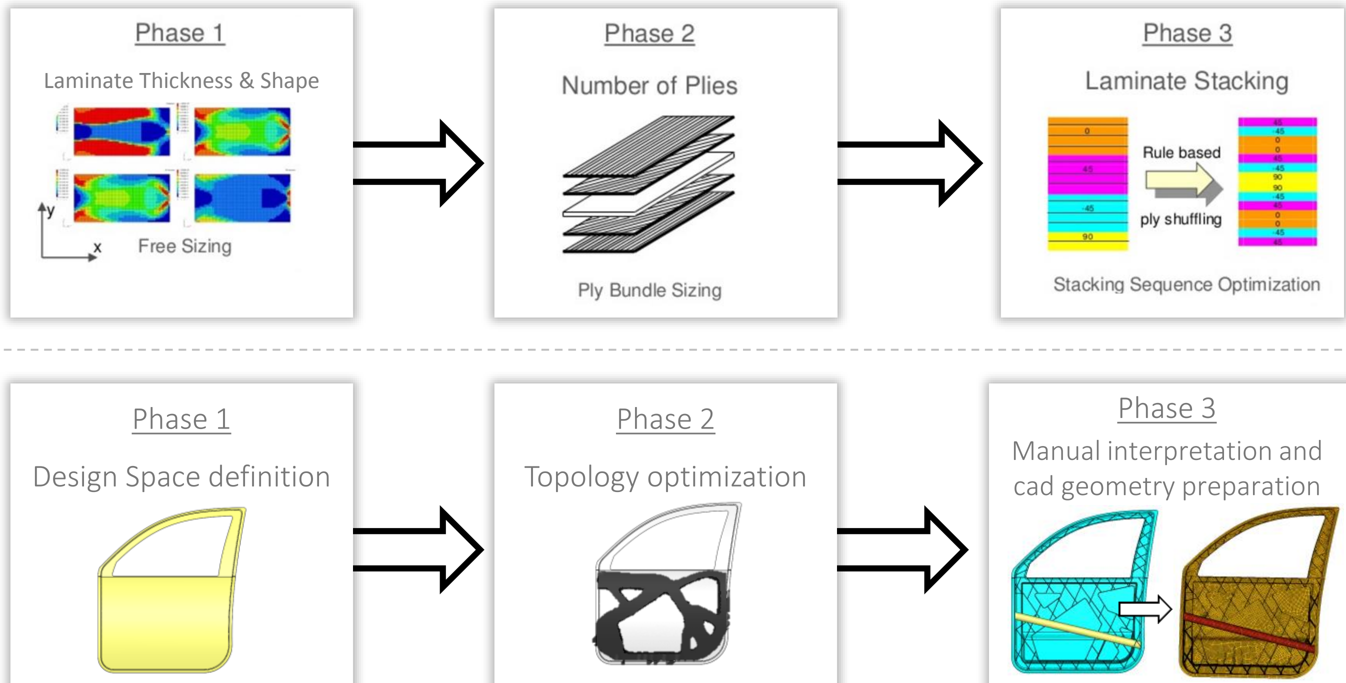
Progress - Structural Performance

Optimization methodology:

- Minimize mass while meeting strength and stiffness requirements.
- Start with a thicker laminate and remove plies till the door no longer meets the stiffness requirements.

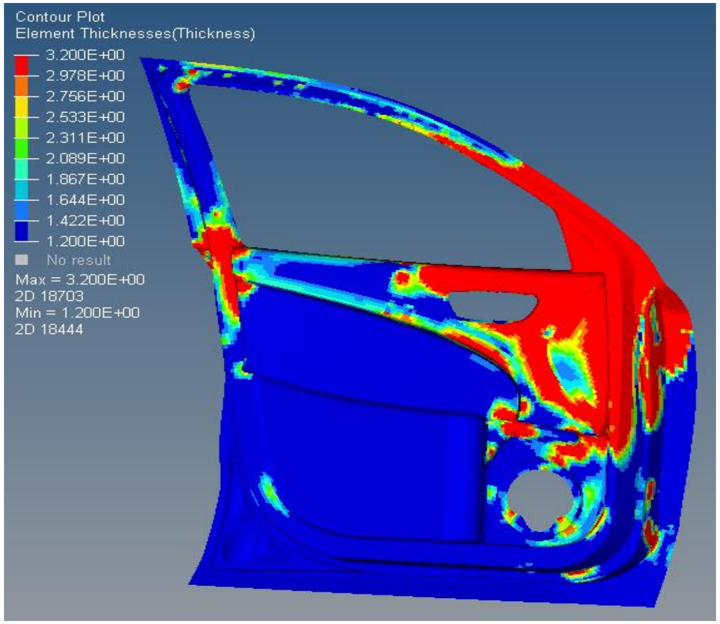
For Endless Fiber reinforced polymer mats and tapes.

For Long Fiber reinforced polymer.



Progress - Structural Performance

- Linear load case represents regular use and occasional miss-use of the door.
  - Use examples: Strong open, window frame stiffness, beltline stiffness, etc.
  - Miss use examples: over opening, door slam, door sag, etc.
- Results: The concept design (slide 11) is based on these optimization results



Thickness plot after laminate optimization

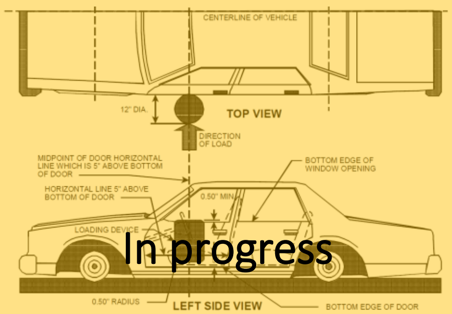
Component	Optimized mass
Inner panel	2.92 kg
Anti intrusion beam	1.72 kg
Inner beltline reinforcement	0.608 Kg
Outer beltline reinforcement	0.414 kg
Class A panel	1.56 kg
Sash reinforcement	0.292 kg
Total optimized mass	**7.51 Kg** ✓
Target	8.44 kg

Progress - Structural Performance

*Images are for example only

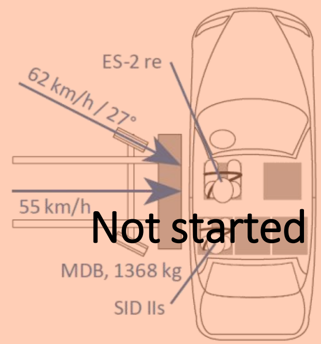
Optimization to minimize mass while meeting non-linear load cases.

1. FMVSS 214s



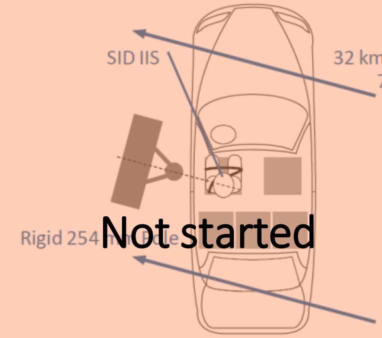
In progress

2. FMVSS 214 (DB)



Not started

1. FMVSS 214 (RP)



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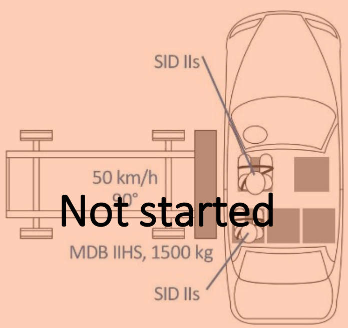
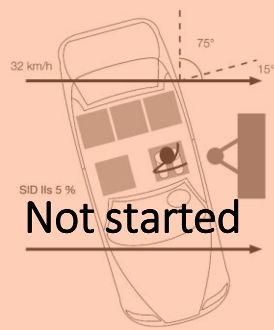
4. IIHS Side impact



Not started

5. U.S NCAP (RP)

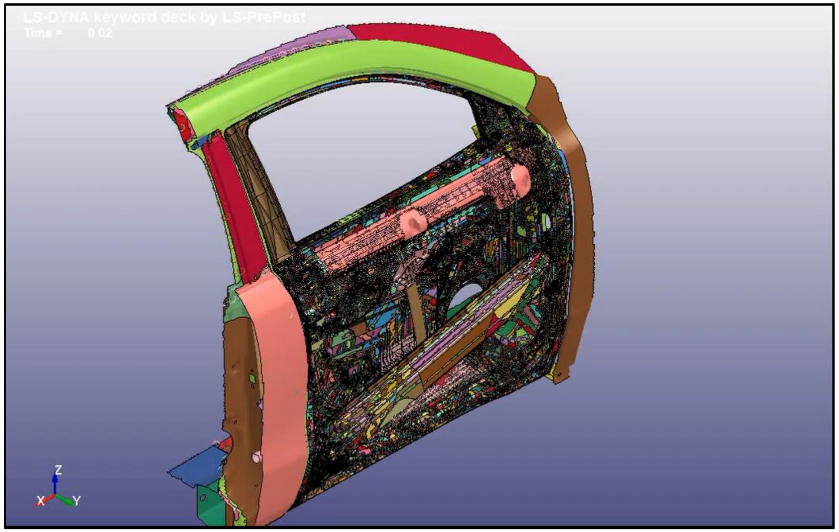


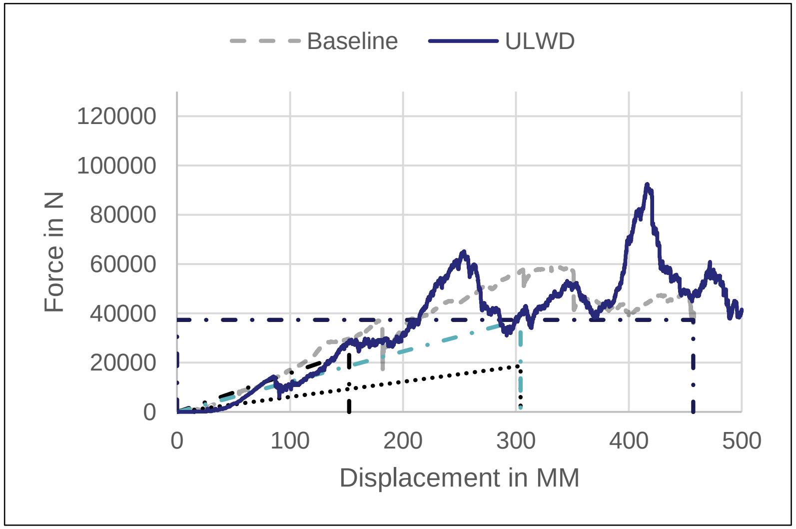
Not started

Progress - Structural Performance

- FMVSS 214 static test was picked as the first non-linear case to optimize
  - This case is the least computationally intense in comparation to the other two crash test. This will enable us to have more design experiments and optimization loops.
  - Meeting this load case will enable the door to almost meet the other two requirements.
  - The door easily meets the federal requirements, but baseline door performance is much higher then federal requirements.

The laminate is not yet optimized for minimizing mass. At the current state the weight of the door is ~12.2kg, and the target is 8.44 kg





Progress - Cost Modelling

From a high level the cost modeling will be performed in three phases, which extend throughout the project duration.

Phase 1

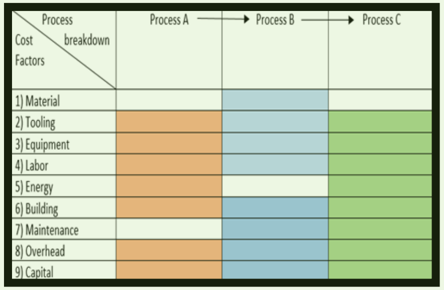
1) Generative modeling

Conceptual design

Carry over parts

In house manufacturing parts

Cost found from available sources



Completed

Phase 2

2) Parametric modeling

This phase will start after the team freezes the final door design concept

In progress

Phase 3

3) Model refinement

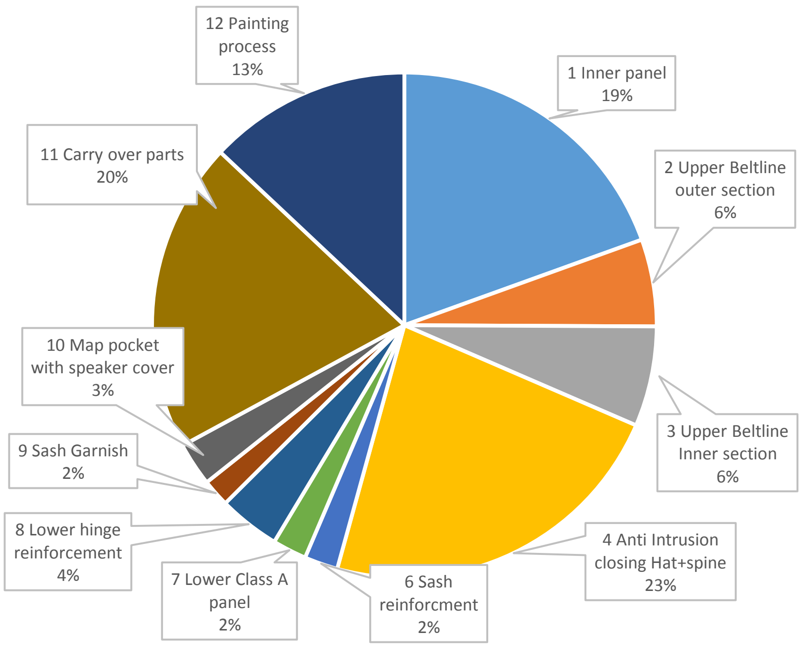
Once the parametric model is finalized, the model will be optimized for minimizing product cost.

Progress - Cost Modelling

Initial costs were estimated using generative models. The team is currently working on developing a virtual factory model in order to better determine the cost of the mass production door.

- Cost of the baseline door: $800
- Approximate Allowable cost increase: $150
- Cost for final selected concept: $919.48 ✓

Sr. No.	Part	Cost in $
1	Inner panel	$179.30
2	Upper Beltline outer section	$51.25
3	Upper Beltline Inner section	$58.94
4	Anti Intrusion closing Hat + spine	$209.69
6	Sash reinforcement	$19.74
7	Lower Class A panel	$20.08
8	Lower hinge reinforcement	$36.20
9	Sash Garnish	$16.24
10	Map pocket with speaker cover	$25.52
11	Carry over parts	$183
12	Painting process	$119.51



Response to Reviewer Comments

Comment from 2017 Annual Merit Review	Responses
"The reviewer remarked that the overall concept of lightweighting a door seems to fly in the face of the first characteristic that needed to be maintained (namely, strong open and close) and asked how does one make a light door feel heavy "	The "strong open and close" was one of the static load cases that was provided by our OEM partner during the first phase of study. More details could not be shared due to IP concerns. While we understand this is an important criteria to meet, we are now focused on enabling more stringent criteria including quasi-static and dynamic load cases.
"The reviewer added that 3-kg attributed to these features (speaker) seems excessive, even if there is no plan to do anything other than outsource that to a different vendor."	The 3 Kg which was attributed to "these features" included the speaker, wire harness. window regulator and latch. The PIs agree with the reviewer that these components do provide a potential for further lightweighting and will focus on them upon finalizing structural components.
The reviewer surmised that if throughput to match steel is "easy," there is not much of a barrier to immediate deployment despite the fact that the earlier comparison table identified thermoplastic composites as being very slow with regard to joining speed, with a "to be determined" (TBD) takt time.	The cycle time to manufacture parts at a component level is close to that of steel and aluminum. Additionally, the PIs have adopted a design consisting of fewer overall parts and easy accessibility for assembly thereby reducing time needed to assemble the door
The reviewer noted, though, that the presentation listed specific collaborators as well as a number of other entities that are contributing and wondered whether this a group of companies are simply being contracted.	A slide providing a detailed list of the roles and responsibilities of every collaborator has been added in the current presentation.

Collaborations

Key Organizations	Role	Responsibilities
Clemson University	Principal Investigator	• Project management • Design development • Manufacturing/tooling design & simulation • Linear & NVH analysis • Cost & factory modeling • Discontinuous fiber material characterization
University of Delaware	Co - PI	• Non-Linear analysis • Manufacturing/tooling design • Continuous fiber material characterization • Design support
Honda The Power of Dreams	OEM Partner	• Target definitions • Student mentoring • Computation support for running complex simulations • Component & vehicle crash testing
Corning	Glazing Partner	• Lightweight glazing design & prototyping • NVH simulation support

Suppliers, software and general participants

PolyOne · BASF We create chemistry · Barrday Advanced Material Solutions · Altair · LSTC Livermore Software Technology Corp. · MSC Software · Moldex3D Molding Innovation · Siemens

Core Participant Profiles

Institution	Advisor	Personal	Standing
CLEMSON UNIVERSITY	Srikanth Pilla	Ting Zheng	Post Doctoral fellow
		Veera Aditya Yerra	PhD students
		Sai Aditya Pradeep	
	Gang Li	Anmol Kothari	
		Madhura Limaye	Masters students
		Pardhvi Shah	
	Srikanth Pilla	Nathaniel Brown	Undergraduate student
University of Delaware	Shridhar Yarlagadda	Bazle Haque	Research Faculty
		Lukas Fuessel	Visiting scholar
HONDA The Power of Dreams	OEM Partner	Duane Detwiler	Chief Engineer
	OEM Partner	Skye Malcolm	Principal Engineer

Remaining Challenges & Barriers

*Any proposed future work is subject to change based on funding levels

- Meeting Crash requirements
  - Composites failure/ energy absorption mechanisms are different than that of steel.
  - Certain parts of the door frame are too stiff. Different materials and ply structures need to be evaluated to solve this.
  - More robust adhesive models are currently implemented to better predict cohesive failures.
- Cost modelling
  - Due to the novelty of these manufacturing processes, determining capital costs is difficult. The team is virtually developing the factory & process layout to determine the capital and operation costs.
- Prototyping
  - Due to large size and complexity of the door frame, very few tooling and manufacturing facilities are capable of prototyping this door frame. These tools are very expensive and the team is currently in talks with various tooling suppliers.

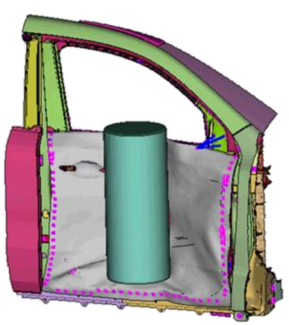
Proposed Future Work

*Any proposed future work is subject to change based on funding levels

1.Dynamic simulations

Refine remaining dynamic simulations and optimize the design to meet the following crash safety requirements.

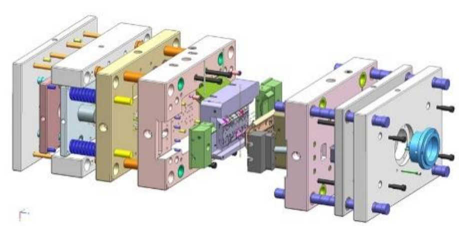
1. FMVSS 214 Rigid Pole
2. FMVSS 214 Deformable Barrier



2.Manufaturing simulations and tooling design

Develop manufacturing simulations, tooling designs and collaborate with tooling and prototyping partners.

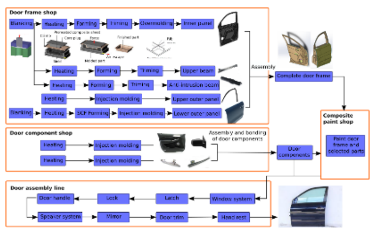
1. Manufacturing simulations for thermoforming and injection molding.
2. Thermoforming tooling and process design
3. Injection molding tool design



3.Mass production plan and cost model refinement

Developing mass production processes and implementing them in a virtual plant layout to determine the costs for the same.

1. Virtual plant layouts for mass production.
2. Developing costing models for estimation and optimization.



Summary

Major goals accomplished in year 2

- Design concept is finalized.
- Design meets all stiffness requirements.
- Cost target would likely be met.

Key Takeaways

- **Weight**
  - 42.5% lightweighting will likely be possible.
- **Targets**
  - Crash performance must be tuned by modifying both the door and body structure. Due to the constraint of this project, only door frame can be modified. This is not a realistic scenario in a real vehicle development project.
- **Cost**
  - The capital cost would be less than classic steel body shops, this might encourage low volume and new manufactures to use these technologies.